



(51) International Patent Classification:

F04D 19/04 (2006.01) F04D 29/057 (2006.01)

F04D 29/051 (2006.01)

(21) International Application Number:

PCT/GB2020/052454

(22) International Filing Date:

05 October 2020 (05.10.2020)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1914605.9 09 October 2019 (09.10.2019) GB

(71) Applicant: EDWARDS LIMITED [GB/GB]; Innovation Drive, Burgess Hill Sussex RH15 9TW (GB).

(72) Inventor: LUCCHETTA, Emiliano; Edwards Limited, Innovation Drive, Burgess Hill Sussex RH15 9TW (GB).

(74) Agent: NORTON, Ian; Edwards Limited, Innovation Drive, Burgess Hill Sussex RH15 9TW (GB).

(81) Designated States (unless otherwise indicated, for every

kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every

kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: VACUUM PUMP COMPRISING AN AXIAL MAGNETIC BEARING AND A RADIAL GAS FOIL BEARING

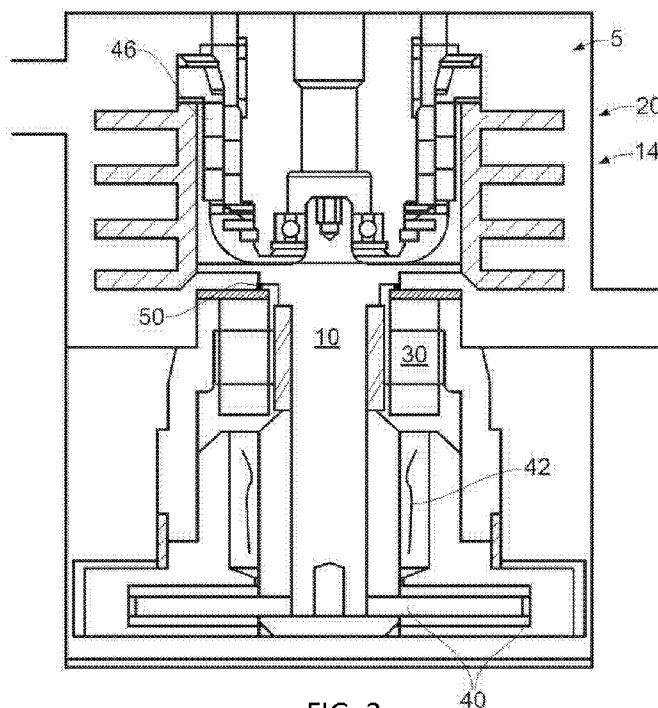


FIG. 2

(57) Abstract: A vacuum pump and method of mounting a shaft within a vacuum pump is disclosed. The vacuum pump comprises a rotor and a stator. The rotor comprises a shaft comprising pumping elements extending therefrom. The shaft is mounted to rotate and is supported by a plurality of bearings, the plurality of bearings comprising: an axial magnetic bearing and two radial bearings, at least one of the two radial bearings comprising a gas foil bearing.

Published:

— *with international search report (Art. 21(3))*

VACUUM PUMP COMPRISING AN AXIAL MAGNETIC BEARING AND A RADIAL GAS FOIL BEARING

FIELD OF THE INVENTION

The field of the invention relates to the field of vacuum pumps.

5

BACKGROUND

Vacuum pumps have rotors that rotate within a stator often at high speeds.

Relatively small clearances between the rotor and stator provide effective pumping. The rotors are supported on a rotatable shaft that is mounted on

10 bearings to provide a low friction and yet stable support for the shaft. Although lubricants may be used to reduce friction there are issues with potential contamination of any vacuum space associated with such lubricants. This provides a further constraint on the design of bearings for supporting the shaft of such a pump.

15

Some fast rotating, high vacuum pumps such as turbomolecular pumps have shafts mounted using five axis active magnetic bearings to provide a low friction and low contamination support for the shaft, the five axis being axially for the axial bearing, and in two radial directions for each radial bearing. These

20 magnetic bearings are however costly.

Gas bearings are an alternative way of mounting a rotating shaft that can allow operation at higher speeds than roller bearings as well as oil-free operation and can provide a more cost effective solution to magnetic bearings. However, gas

25 bearings do need to be sealed from the vacuum space, and they may have a high torque requirement on start-up, which may require an increased motor size. They may also have higher losses at the operating speed and increased cooling requirements.

30 It would be desirable to be able to mount the shaft of a vacuum pump on bearings that provide a low friction, low contamination, low torque and power solution without unduly high costs or high cooling requirements.

SUMMARY

5 A first aspect provides a vacuum pump comprising a rotor and a stator, said rotor comprising a shaft comprising pumping elements extending therefrom; said shaft being mounted to rotate and being supported by a plurality of bearings, said plurality of bearings comprising: an axial magnetic bearing; and two radial bearings, at least one of said two radial bearings comprising a radial gas foil bearing.

10

As noted above the requirements for vacuum pump bearings are quite challenging. In particular, the bearings should be able to operate at high speeds, and therefore non-contacting bearings are preferred, they should preferably be lubricant free, and they should provide stability for the rotor, which is required due to the small clearances in the pump.

15

The inventor of the present invention recognised that gas bearings have many of the attributes required for a bearing supporting a shaft of a vacuum pump, in that they are non-contacting bearings, they are low maintenance, they operate effectively at high speeds, they provide damping and they do not require lubrication.

20

Gas bearings operate in either an aerodynamic or aerostatic manner. When operating in an aerostatic manner, compressed gas is input into the bearing to provide the clearances required for non-contact operation. Adding gas to a component of a vacuum system is generally not desirable. In gas bearings that operate in an aerodynamic manner it is the rotational motion that provides the aerodynamic operation and the clearances. This has the advantage of allowing the bearing to operate without the requirement of adding compressed gas to a vacuum pump, but has the disadvantage that the bearings only operate in a low friction manner at speeds high enough for the aerodynamic properties to become effective. Furthermore, aerodynamic gas bearings that do not use compressed

25

30

- 3 -

gas generally require small clearances which in environments which experience temperature changes may be problematic, they may also have some instability. Gas foil bearings address these two problems by in effect providing a compliant gap between the two surfaces, making them less prone to instability and

5 providing effective damping. This makes them particularly effective for vacuum pump use. A gas foil bearing is a type of gas bearing with a compliant spring-loaded foil lining between the surfaces of the bearing. At a certain speed of rotation gas within the bearing pushes the foil away from the rotating shaft so that no contact occurs. However, despite these advantages significant torque is
10 required to initially rotate a shaft mounted on a gas foil bearing, the torque reducing when a speed sufficiently high for aerodynamic operation is attained. Thus, the use of such bearings within a vacuum pump would require a significantly larger motor than is conventionally used for this initial rotation.

15 The inventor of the present invention recognised that the increased torque requirement associated with gas foil bearings was particularly high for the axial bearing, as the axial bearing is likely to see higher loads than the radial bearing and has a significantly larger radius than the radial bearings do. Thus, he realised that were a hybrid system to be used where the axial bearing was a
20 magnetic bearing configured to magnetically support and levitate the shaft and at least one of the radial bearings was a gas foil bearing, then the advantages of the gas foil bearings in providing a low cost, high speed, non-contacting, high damping bearing would be provided with the associated disadvantage of increased starting torque being reduced owing to the bearing
25 that generally provides the greatest contribution to this, that is the axial bearing, being a magnetic bearing. In effect the combination of bearings supports the shaft in a way that provides the advantages of both types of bearing, while mitigating many of the disadvantages.

30 In some embodiments, said axial magnetic bearing comprises an axial active magnetic bearing.

- 4 -

Although the axial magnetic bearing or axial magnetic levitation bearing may be a passive magnetic bearing in some embodiments it is an active magnetic bearing, allowing control of the levitation provided by the bearing.

- 5 In some embodiments, the vacuum pump comprises two radial gas bearings, one of them being a radial gas foil bearing, in some embodiments both radial bearings are radial gas foil bearings.

- 10 In order to provide five axis stability the shaft of a vacuum pump may be mounted on two radial and one axial bearing. The two (or more) radial bearings may be radial gas bearings, in some cases gas foil bearings. Gas foil bearings have the advantages of high speed operation, stability and low friction at higher operational speeds. Their disadvantages lie in the higher torque required for their initial rotation due to higher friction prior to reaching aerodynamic speeds, 15 this disadvantage is lower for radial than it is for axial bearings.

In other embodiments, said radial bearings comprise a radial magnetic bearing and a radial gas foil bearing.

- 20 Although two radial gas foil bearings may provide effective radial stability for the shaft of a pump, in some embodiments, a radial magnetic bearing may be used for one of the radial bearings, with a gas bearing being used for the other. A magnetic bearing has many of the advantages of a gas bearing, being non-contact and low friction. It has the additional advantages of being able to operate 25 in a high vacuum environment and provides low friction even at low speeds. The combination of a gas bearing and magnetic bearing may provide reduced torque at initial speeds, increased damping and more freedom in the placement of the bearings.
- 30 In some embodiments, said radial magnetic bearing comprises a passive magnetic bearing.

- 5 -

A passive magnetic bearing is generally less expensive than an active magnetic bearing and may provide effective support for the shaft. Such a bearing may not provide effective damping, but such a disadvantage may be mitigated if the bearing is used in conjunction with a radial gas foil bearing.

5

In some embodiments, said magnetic bearing is located close to a portion of said shaft supporting said pumping elements and said radial gas foil bearing is located remotely from said portion of said shaft supporting said pumping elements.

10 In some embodiments said pumping elements comprise rotor blades.

In some embodiments, said vacuum pump further comprises a seal to seal a portion of said vacuum pump comprising said pumping elements from a portion of said vacuum pump comprising said at least one radial gas foil bearing.

15

As noted above the radial gas foil bearing does not operate well in a vacuum environment and thus, may be located in area that is sealed from the pumping chamber in cases where the vacuum pump does not exhaust to atmosphere.

20 In some embodiments, said vacuum pump comprises a sealing element to seal a portion of said vacuum pump comprising said pumping elements and said magnetic bearing from a portion of said vacuum pump comprising said radial gas foil bearing.

25 The magnetic bearing however, can operate at low pressure, thus, where one radial bearing is a magnetic bearing it may be advantageous to mount this adjacent to the pumping chamber and to provide a seal, in some embodiments a rotary shaft seal, between the two radial bearings such that the magnetic one operates in the vacuum environment and the other at a higher pressure.

30

- 6 -

In some embodiments, said vacuum pump, further comprises a motor for rotating said shaft, said motor being mounted between said radial gas foil bearing and the further radial bearing.

- 5 Where there are two radial bearings it may be convenient to mount them on either side of the motor such that they are axially displaced from each other and provide effective support. The motor may be sealed from the pumping chamber of the vacuum pump where the vacuum pump does not exhaust to atmosphere and thus, the vacuum pump may comprise a seal to seal the pumping elements
10 from the radial bearings and the motor.

In some embodiments said vacuum pump comprises a turbomolecular pump.

- Turbomolecular pumps operate at high rotational speeds and thus, gas foil
15 bearings which are non-contacting and which require high speeds to operate well are particularly effective with these pumps. Turbomolecular pumps do not however, exhaust to atmosphere and thus, in some embodiments, a gas foil radial bearing as one bearing and a magnetic bearing as the bearing adjacent to the pumping chamber of the vacuum pump may be a particularly advantageous
20 arrangement.

- A second aspect provides a method of mounting a shaft of a rotor of a vacuum pump, said method comprising: supporting said shaft with an axial magnetic bearing and with two radial bearings, at least one of said radial bearings
25 comprising a radial gas foil bearing.

- Further particular and preferred aspects are set out in the accompanying independent and dependent claims. Features of the dependent claims may be combined with features of the independent claims as appropriate, and in
30 combinations other than those explicitly set out in the claims.

- 7 -

Where an apparatus feature is described as being operable to provide a function, it will be appreciated that this includes an apparatus feature which provides that function or which is adapted or configured to provide that function.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described further, with reference to the accompanying drawings, in which:

Figure 1 shows a rotor of a vacuum pump according to an embodiment; and
Figure 2 shows a vacuum pump according to a further embodiment.

10

DESCRIPTION OF THE EMBODIMENTS

Before discussing the embodiments in any more detail, first an overview will be provided.

- 15 Vacuum pumps that have shafts supported by five axis active magnetic bearings provide an effective, oil free bearing system that is however, expensive. As an alternative to a 5 axis active magnetic bearing oil free system some vacuum pump use a 1 axis active system, that is a system with an active axial magnetic bearing and with 2 passive radial magnetic bearings. Such a system takes
20 advantage of the relatively low cost of a simpler 1 axis system. However the cost of the permanent magnets for the radial bearings is still significant and these bearings also inherently provide low damping. Such a system therefore requires additional dampers and/or may have limited operating conditions.
- 25 An alternative is the use of gas bearings, in particular gas foil bearings for the 2 radial and the 1 axial, double acting active bearing. However, the power losses and the starting torque of such an arrangement is high and this may be an issue for certain vacuum pumps.
- 30 The inventor of the present invention recognised that a high proportion of the losses and high starting torque of a system supported by gas foil bearings comes from the axial foil bearing, which has a higher load and a relatively large radius

- 8 -

when compared to the radial bearings. Thus, these competing problems have been addressed by providing a system that uses a 1 axis axial magnetic bearing for the axial bearing, with radial bearings at least one of which is a gas foil bearing. Such a system combines the benefits of both technologies to provide
5 an effective and lower cost solution for high speed vacuum pumps.

If a seal is required to separate the bearings from the vacuum (i.e. if the pump is not exhausting to atmosphere but to vacuum pressure, such as is the case for a turbomolecular pump) a shaft rotary seal can be used. In some embodiments the
10 rotary seal may be a foil seal.

A vacuum pump is disclosed whose shaft is supported by a combination of different bearing technologies which include:

- an axial magnetic bearing, preferably an active magnetic bearing to
15 support the shaft axially
- 2 radial bearings to support the shaft radially, at least one of which is a gas foil bearing.

In some embodiments, the pump is provided with a shaft rotary seal to separate
20 the gas bearings from the vacuum and provide the necessary conditions for gas bearings to work; this may be a foil seal using the same principles as the gas foil bearing.

Figure 1 schematically shows a vacuum pump 5 according to an embodiment. In
25 this embodiment the vacuum pump is a turbomolecular pump. Turbomolecular pump 5 comprises a shaft 10 supporting a rotor 12 with pumping elements 14 extending therefrom within a stator (not shown). The shaft 10 is driven by motor 30 and is rotatably mounted within a pump housing by magnetic axial bearing 40 and two radial bearings 42 and 44. In this embodiment the lower bearing 42
30 comprises a gas foil bearing as does the upper bearing 44. In other embodiments one of the two bearings may be a different type of bearing such as a roller bearing or a different type of gas bearing.

- 9 -

The motor 30 and bearings 40, 42 and 44 are separated from the vacuum enclosure of the vacuum pump by a vacuum seal 50.

5 Gas foil bearings provide low friction operation when rotating at speeds sufficient for aerodynamic operation, however, at lower speeds such as at startup they require considerable torque for rotation. The use of a magnetic axial bearing 40, which as can be seen has a relatively large radius, significantly reduces the torque required to initiate rotation of the rotor when compared to one mounted
10 exclusively on gas foil bearings and results in a system that can operate with a motor 30 that is of a similar size to a conventional motor for such a vacuum pump. The use of the gas foil bearings provides non-contacting bearings with good damping and vibration resistance. Their operation at high speed is particularly effective and allows the vacuum pump to operate effectively and
15 power efficiently. Gas foil bearings operate at atmospheric pressure, and thus, a vacuum seal 50 is used to isolate the vacuum enclosure and the bearings. Mounting the motor between the bearings provides axial displacement of the two radial bearings allowing for more stable support of the shaft. Furthermore, the motor 30 is isolated from the vacuum enclosure by the same vacuum seal 50 that
20 isolates the gas foil bearings.

Figure 2 shows an alternative embodiment where there is a magnetic axial bearing 40 supporting the shaft and two radial bearings. One of the radial bearings 42 is a gas foil bearing. In this case, the upper radial bearing 46 is a
25 magnetic bearing and is within the vacuum enclosure. Seal 50 is located between the two radial bearings 42, 46. In this embodiment, the upper radial magnetic bearing 46 is a passive magnetic bearing while the lower axial magnetic bearing 40 is an active magnetic bearing. However, either bearing could be passive or active according to the embodiment.

30

An advantage of having the upper bearing 46 as a magnetic bearing is that it can be within the vacuum enclosure and allows the two radial bearings to be spaced

- 10 -

apart and the seal 50 to be located between the two bearings. Although magnetic bearings can be more expensive than gas foil bearings they do provide different properties and the gas foil bearing will provide resistance to vibrations and effective damping while the magnetic bearing will provide a lower starting torque and it is possible to place it within the vacuum environment.

Although illustrative embodiments of the invention have been disclosed in detail herein, with reference to the accompanying drawings, it is understood that the invention is not limited to the precise embodiment and that various changes and modifications can be effected therein by one skilled in the art without departing from the scope of the invention as defined by the appended claims and their equivalents.

- 11 -

REFERENCE SIGNS

	5	vacuum pump
	10	shaft
	12	rotor
5	14	pumping elements
	20	stator
	30	motor
	40	magnetic axial bearing
	42, 44	gas foil radial bearings
10	46	magnetic radial bearing
	50	seal

CLAIMS

1. A vacuum pump comprising a rotor and a stator, said rotor comprising a shaft comprising pumping elements extending therefrom;

5 said shaft being mounted to rotate and being supported by a plurality of bearings, said plurality of bearings comprising:

two radial bearings, at least one of said two radial bearings comprising a radial gas foil bearing; and

an axial magnetic bearing.

10

2. A vacuum pump according to claim 1, wherein said axial magnetic bearing comprises an axial active magnetic bearing.

3. A vacuum pump according to any preceding claim, wherein said two radial
15 bearings comprise gas bearings.

4. A vacuum pump according to claim 3, wherein said two radial bearings comprise radial gas foil bearings.

20 5. A vacuum pump according to any one of claims 1 or 2, wherein said two radial bearings comprise said gas foil bearing and a radial magnetic bearing.

6. A vacuum pump according to claim 5, wherein said radial magnetic bearing comprises a radial passive magnetic bearing.

25

7. A vacuum pump according to claim 5 or 6, wherein said radial magnetic bearing is located close to a portion of said shaft supporting said pumping elements and said radial gas foil bearing is located remotely from said portion of said shaft supporting said pumping elements.

30

8. A vacuum pump according to any preceding claim, said vacuum pump further comprising a seal to seal a portion of said vacuum pump comprising said

- 13 -

pumping elements from a portion of said vacuum pump comprising said at least one radial gas foil bearing.

9. A vacuum pump according to any one of claim 7, said vacuum pump
5 comprising a sealing element to seal a portion of said vacuum pump comprising said pumping elements and said magnetic bearing from a portion of said vacuum pump comprising said radial gasfoil bearing.

10. A vacuum pump according to any preceding claim, said vacuum pump,
10 further comprising a motor for rotating said shaft, said motor being mounted between said two radial bearings.

11. A vacuum pump according to any preceding claim, said vacuum pump
being configured to operate in an orientation where said shaft extends vertically
15 and said axial magnetic bearing is configured to support and levitate said shaft.

12. A vacuum pump according to any preceding claim, wherein said vacuum pump comprises a turbomolecular pump.

20 13. A method of mounting a shaft of a rotor of a vacuum pump, said method comprising:
supporting said shaft with an axial magnetic bearing and with two radial bearings,
at least one of said two bearings comprising a radial gas foil bearing.

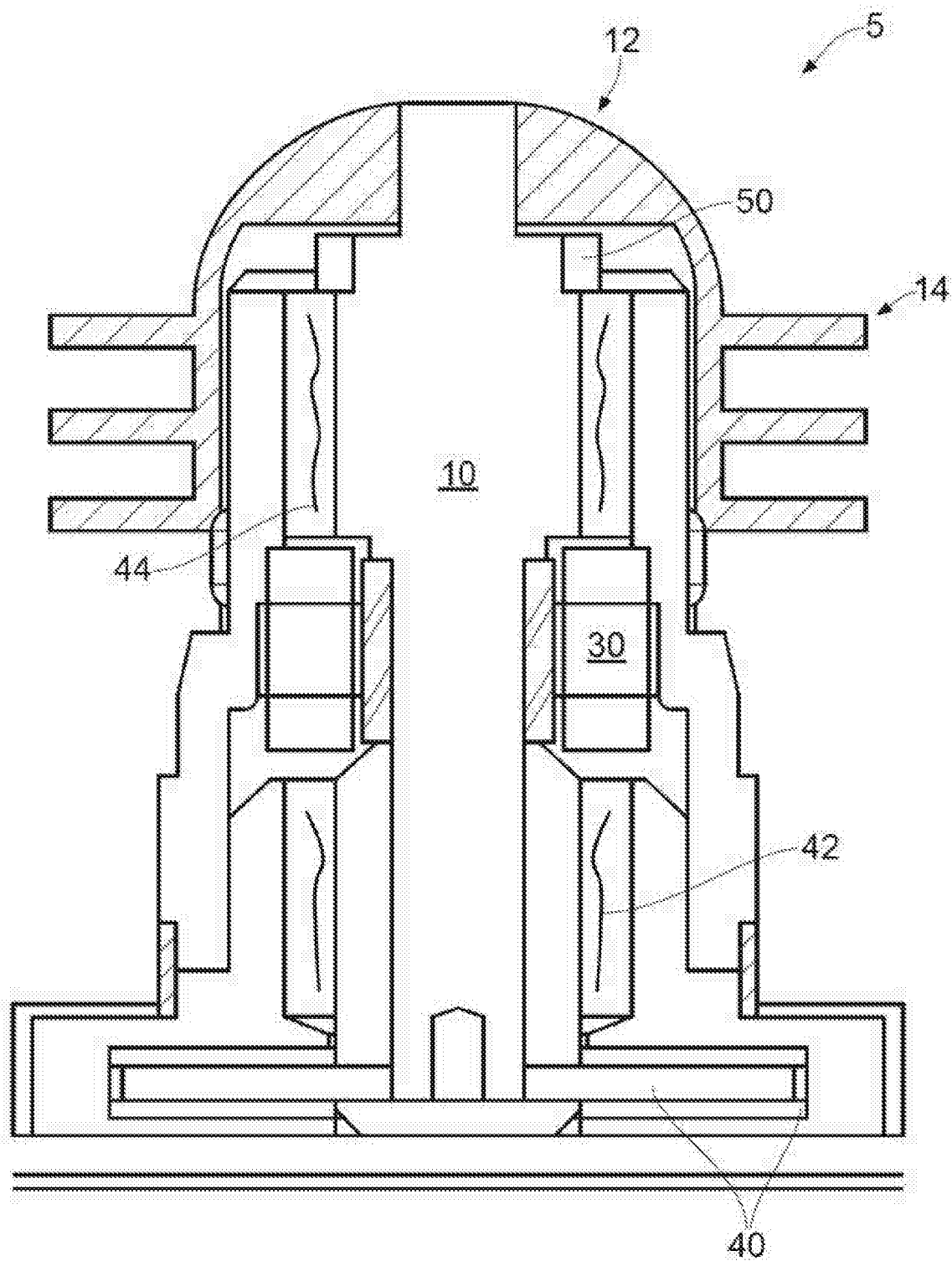


FIG. 1

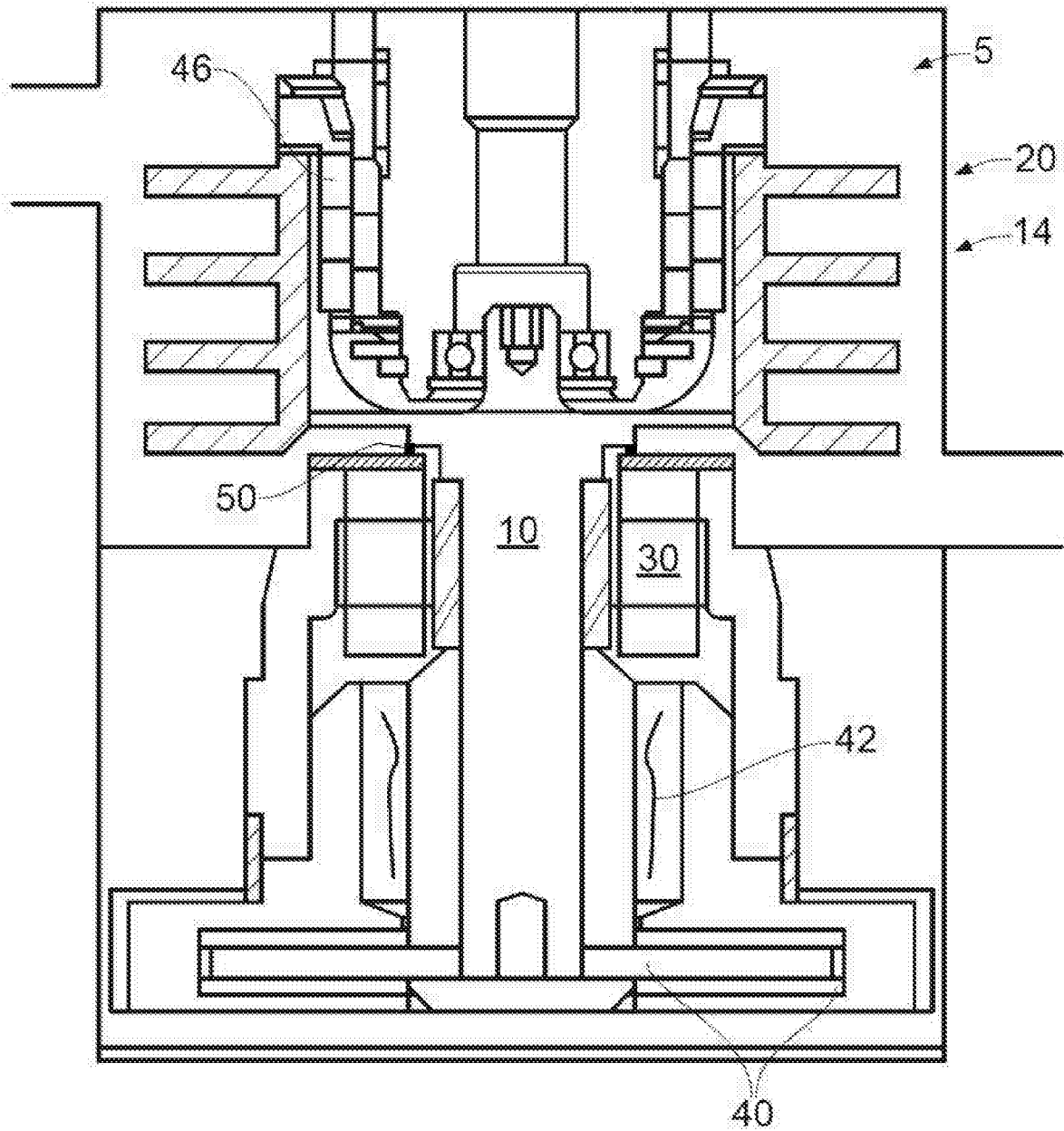


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/052454

A. CLASSIFICATION OF SUBJECT MATTER

INV. F04D19/04 F04D29/051 F04D29/057
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04D F16C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP H11 166530 A (SHIMADZU CORP) 22 June 1999 (1999-06-22) abstract figure 5	1-5,7,8, 10-13 6,9
X Y	JP 2002 168249 A (SHIMADZU CORP) 14 June 2002 (2002-06-14) abstract figures 1-4	1-4,8, 10-13 5-7,9
Y	JP H10 288187 A (SHIMADZU CORP) 27 October 1998 (1998-10-27) abstract figure 1	1-13
	----- -/--	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

30 November 2020

Date of mailing of the international search report

08/12/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Oliveira, Damien

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2020/052454

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP H10 292818 A (SHIMADZU CORP) 4 November 1998 (1998-11-04) abstract figure 1 -----	1-13
Y	US 2007/069597 A1 (TANIGUCHI MANABU [JP] ET AL) 29 March 2007 (2007-03-29) paragraph [0011] paragraph [0030] paragraph [0043] - paragraph [0045] paragraph [0048] - paragraph [0049] figures 2-4, 6, 7 -----	1-13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2020/052454

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP H11166530 A	22-06-1999	JP 3997578 B2	24-10-2007
		JP H11166530 A	22-06-1999
JP 2002168249 A	14-06-2002	NONE	
JP H10288187 A	27-10-1998	NONE	
JP H10292818 A	04-11-1998	NONE	
US 2007069597 A1	29-03-2007	EP 1770284 A2	04-04-2007
		JP 2007092646 A	12-04-2007
		US 2007069597 A1	29-03-2007